

FINAL REPORT FOR NASA AWARD NAGW-~~1490~~

DEVELOPING A STAND ALONE SUN PHOTOMETER FOR SHIPS AND BUOYS

John N Porter (PI)

UNIVERSITY OF HAWAII
SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY
HAWAII INSTITUTE OF GEOPHYSICS AND PLANETOLOGY
2525 CORREA ROAD
HONOLULU, HAWAII 96822
FAX (808) 956-3188
PHONE (808) 956-6483
EMAIL: porter@soest.hawaii.edu

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BACKGROUND

During November and December 1995 the first Aerosol Characterization Experiment (ACE1) was carried to characterize the aerosol physical and optical properties in the clean marine atmosphere near Tasmania in the South Pacific. As part of this effort, and with funding from this proposal, we installed a sun photometer on the R/V Discoverer and a spectro-photometer on the NOAA C-130 aircraft.

SHIP SUN PHOTOMETER

The ship sun photometer is based on a scientific grade CCD camera which is used to image the sun with a ~20 degree field of view. The camera has a filter wheel with eight filters ranging from 400 to 1020 nm. The CCD chip has fourteen bit digitization and is cooled with two thermo-electric coolers which control the temperature to within 0.1 degree celcius. The integration time is variable down to 10 msec time. In order to ensure no wavelength shifts occur in passing through the filters, a pin hole (~10 mm diameter) is mounted in front of the outer lens. This causes the light to pass through only the center of the lens and straight through the filters. While the external pin hole causes less wavelength shifts, it causes a stronger roll off effect (vignetting). This is illustrated in figure 1 which shows a flat field measurement made with a spectralon plaque. The flat field measurements are made at Mauna Loa observatory where low aerosol optical depth causes the direct solar beam to be much larger than the diffuse light and it assumed that the solar light has parallel rays. Calibration of the CCD camera is obtained by making Langley plots measurements at the Mauna Loa observatory. An example of the CCD Langley plot is shown in Figure 2.

In order to point the camera at the sun on a moving ship, a two axis motor is used which is controlled by a computer. The orientation of the sun, with respect to the camera, is obtained from

the position of the sun in a second fish eye camera. The average x-y position of the sun in the fish eye image gives the azimuth and zenith angles of the sun relative to the ship. During the ACE1 experiment, the instrument was able to track the sun successfully. Unfortunately the software had bugs and several bits in the solar images were lost. This prevented the proper measurement of the aerosol optical depth. Following the experiment, many hours were spent to develop robust c subroutines which would control the CCD camera and process the images. In particular it was necessary to carry out careful statistical studies to flag pixels with irregular response. A paper describing the approach is currently being developed and will be submitted in the near future. We are also developing a new approach to derive the aureole by blocking the direct solar beam with a rotating shadowband which arm passes over both the camera and a fast response detector. When the fast response detector senses the decrease in light due to the detector, then it sends a pulse to the camera to make a measurement.

AIRCRAFT MEASUREMENTS

During ACE1, numerous aerosol measurements were made on the NCAR C130 aircraft including size distributions, chemical composition and vertical distribution (LIDAR). The aircraft flew from 30 m to 5 km altitude providing an excellent data set to test and validate optical aerosol retrieval algorithms. In order to complement the aircraft measurements, a downward looking spectrometer was mounted on the aircraft. The spectrometer had 250 wavelength channels ranging from 400 to 1100 nm with 7 nm FWHM. High signal to noise was maintained by auto scaling the integration time. This allowed for good measurements of low light conditions when looking at the ocean surface and avoided saturation when looking at highly reflective clouds. The field of view of the spectrometer was 5 degrees. Calibrations were carried using an integrating sphere looking through the aircraft window. Cross comparisons were carried out between radiance several independent NIST traceable standards. The final radiance values have an absolute accuracy of 6-7%. The 26 flights were processed and put in the ACE1 archive for use by the radiation community. An example of the data is shown in Figure 3 which shows the upwelling radiance seen as the aircraft climbs and drops over two regions with different wind speeds. The first period when the aircraft was near the surface had wind speeds of 6 m/s with significant specular reflection. The second period near the surface, the surface winds were 2.5 m/s and little variation in the surface upwelling radiance is seen. The 450 nm wavelength also shows large variations which appear less at 550 nm and are not present at 700 nm. These spatially varying ocean color features appear clearly both near the surface and when the aircraft is at 3.5 km altitude.

As part of our ACE1 effort we are seeking radiative closure from the different data sets. Figures 4 and 5 illustrate this effort. Figure 4 shows the upwelling radiance measured with the spectrometer as the aircraft climbed and then descended back down to the surface. Taking the difference between the upper level and surface upwelling radiance we calculate an aerosol optical depth of 0.035 at 630 nm. This effort assumed an aerosol phase function based on the marine aerosol

models of Porter and Clarke (1997). Figure 5 shows the aerosol scattering coefficient calculated from aerosol size distributions measured on the aircraft. Integrating these values with height gives an aerosol optical depth 0.033 at 630 nm and 0.038 at 500 nm. Coincident sun photometer measurements on the Discoverer R/V gave 0.038 suggesting reasonable agreement. We are currently using the upwelling radiance to test our ability to derive the column aerosol phase function and the wavelength dependence of the upwelling radiance. These closure efforts will be submitted in a future paper.

REFERENCES

Porter, J.N. and A.D. Clarke, Aerosol Size Distribution Models Based On Insitu Measurements: Aerosol Backscatter Calculations, submitted to J. Geophys. Res., 1996.

Porter, J.N., A.D. Clarke and P. Flament, Deriving Aerosol Optical Properties Over the Ocean From AVHRR Satellites: Modeling Studies and Validations, submitted to J. Geophys. Res., 1996.

Figure 1. A flat field image taken with our scientific grade CCD camera. The large amount of vignetting is caused by the pin hole configuration we employ.

Figure 2. A Langley plot taken at Mauna Loa observatory with a NOAA hand held sun photometer and the CCD camera. For the CCD camera, the values of the center of the sun were averaged together. Flat field and dark count corrections are made to the image before this determining the sun value. Pixels which are routinely different from the others are also flagged and not used in deriving the sun optical depth.

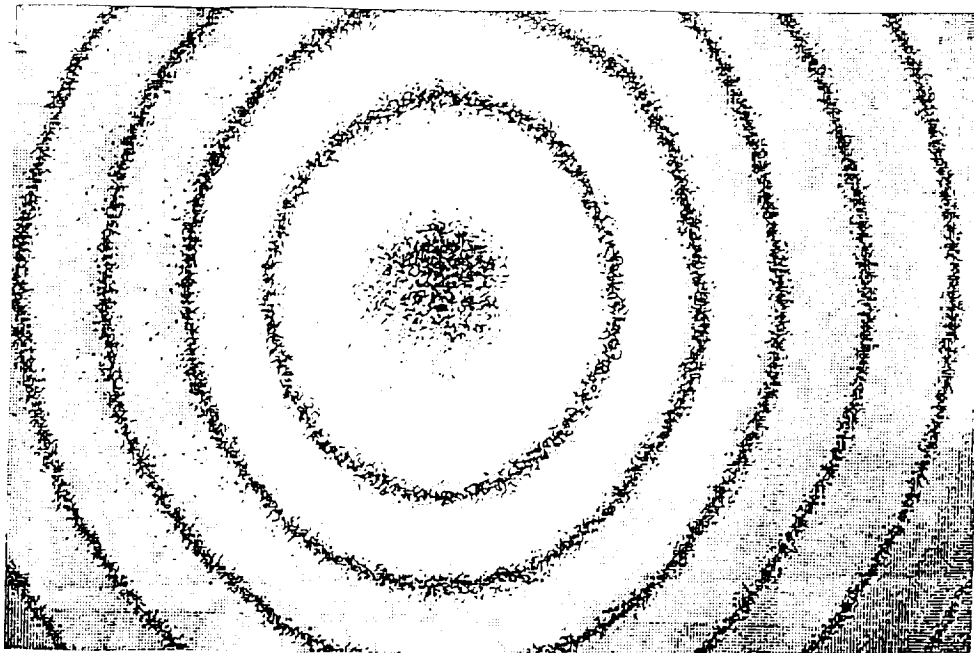


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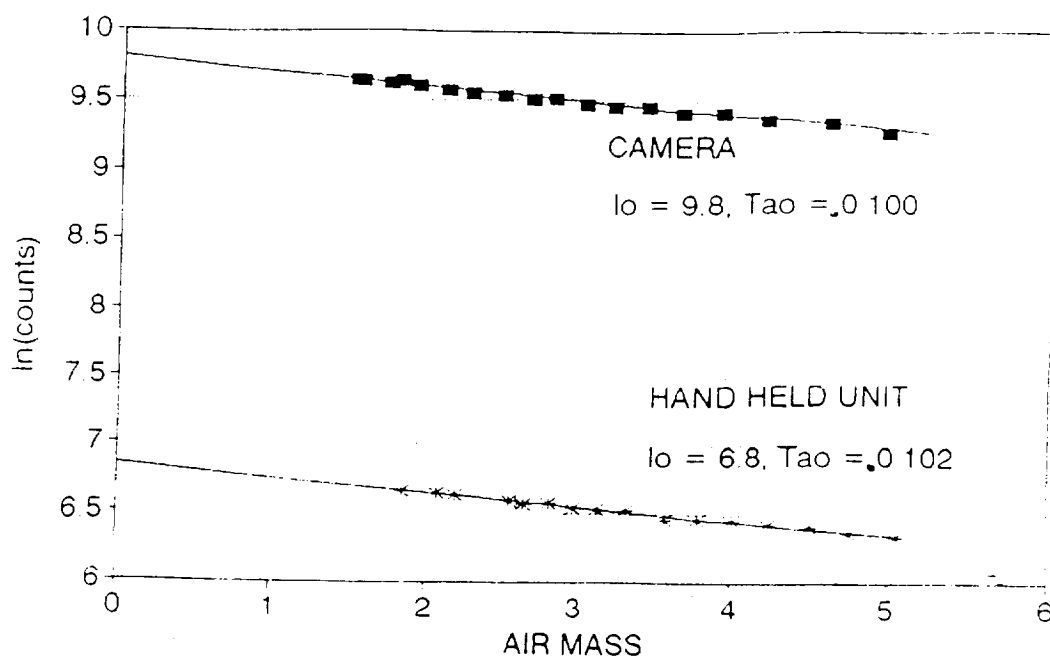


Figure 2. A Langley plot taken at Mauna Loa observatory with a NOAA hand held sun photometer and the CCD camera. For the CCD camera, the values of the center of the sun were averaged together. Flat field and dark count corrections are made to the image before this determining the sun value. Pixels which are routinely different from the others are also flagged and not used in deriving the sun optical depth.

ACE1 FLIGHT 14, DAY 328

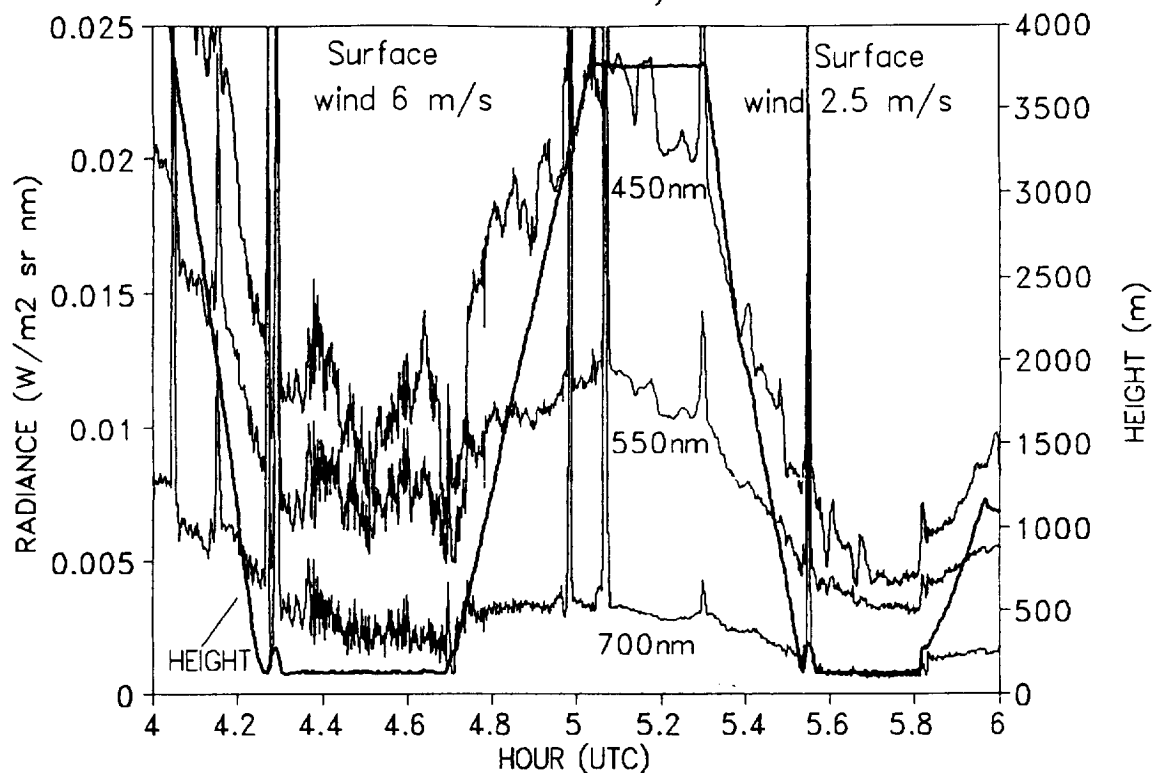


Figure 3. An example of the upwelling radiance measurements made on the NCAR-C130 aircraft. The black line shows the aircraft height and the blue, green and red lines show the measured upwelling radiance at 450, 550 and 700 nm. The surface wind speed was 6 m/s and 2.5 m/s the two times the aircraft was near the surface.

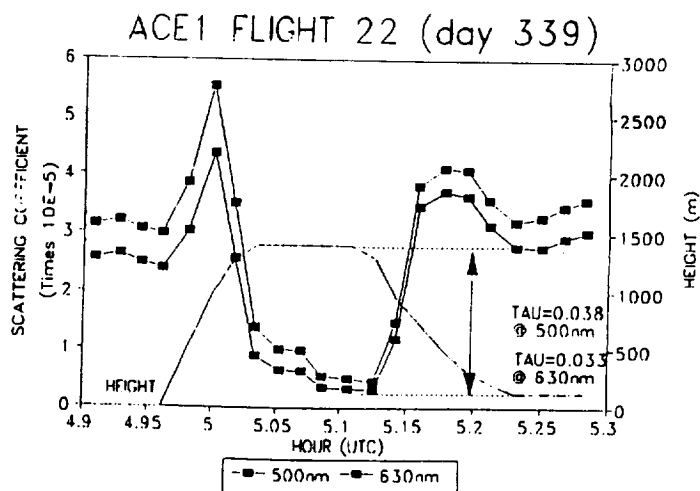
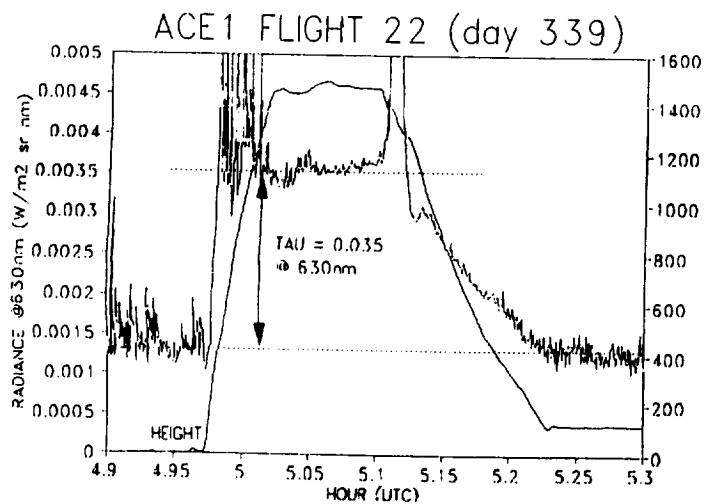


Figure 4. The left panel shows the upwelling radiance at 630 nm. Based on the radiance difference between the surface and 1500 m we calculate an aerosol optical depth of 0.035. The right panel shows the aerosol scattering coefficient (500 and 630 nm) calculated from aerosol size distributions. Integrating the scattering coefficient gives an aerosol optical depth of 0.038 at 500 nm and 0.033 at 630 nm which is good agreement with the values derived from the spectrometer.